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Geopressure zones throw challenge to drillers in three Canadian plays

Drilling in western Canada has had its surprises, but one "old" and two new frontier areas have thrown a completely new challenge at Canadian drillers — "geopressure zones", or intervals with abnormally high formation pressures.

In Canada they occur off the west coast, where Shell Canada Ltd. first had to tangle with them, off the east coast under the Nova Scotian Shelf, and in the Mackenzie Delta area. They have been known to occur in areas of rapid sedimentation, mud and salt diapirs, and likely in deeper intervals.

Occurrences of geopressure zones lead to specifically designed casing and mud programs, completion techniques, stockpiling of heavy mud materials, and most importantly, very intensive instruction of supervisory and field drilling personnel.

Drilling in areas where geopressure zones occur will always be touchy, since mud programs cannot be overdesigned for fear of damage to overlying for-

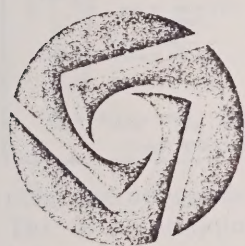
By HORST HEISE
Exploration Editor

mations or to casing. And deep drilling depth also limits the extension of successive casing intervals that could protect overlying formations against too heavy a mud column. What is required, then, is a balanced mud system, or just enough mud weight to contain formation pressures, with a keen eye to any signs of pressure increase. And that requires skill, thorough knowledge and cunning use of the tools and methods already available to the drilling profession.

All major operators in the frontier areas stress one point in particular: the drilling crews must be thoroughly familiar with the equipment and perfectly capable of handling a "kick" any time it comes. The PITS training course is invariably mentioned and at least one operator puts his personnel plus all crews of rigs contracted through additional drills on a simulator.

The same philosophy of preparedness governs all other preparations on a rig. Not only the casing programs, but also standby procedures (already mixed reserve mud, for instance) have all one aspect in common: expect the kick, and then act.

Why not act before a kick to prevent it? Because it would not only be far more expensive, but would also cause severe damage in many ways. It might fracture a formation in the borehole when the formation's own pore pressure and competency is surpassed. This might not just invade the zone and wash out the hole over the affected interval, likely completely messing up the hole at that point, it will almost certainly cause a downhole blowout if high pressure zones are penetrated by the bit below the fractured formation. Besides, heavier drilling mud will require stronger casing to a deeper depth than is necessary, will considerably slow down penetration rates and will mask events



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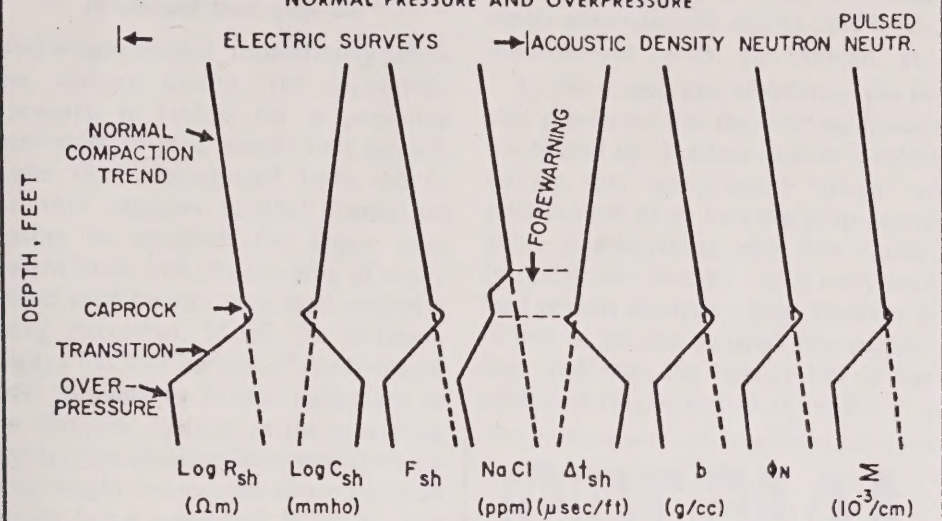
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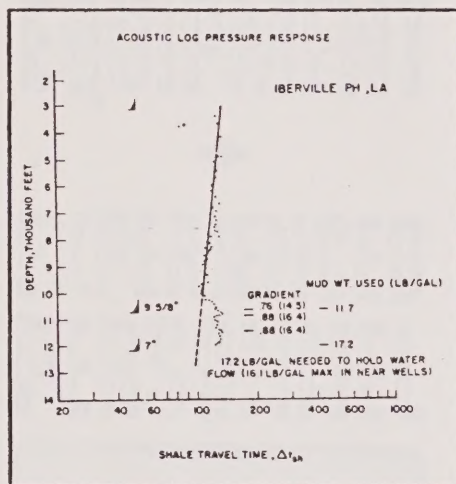
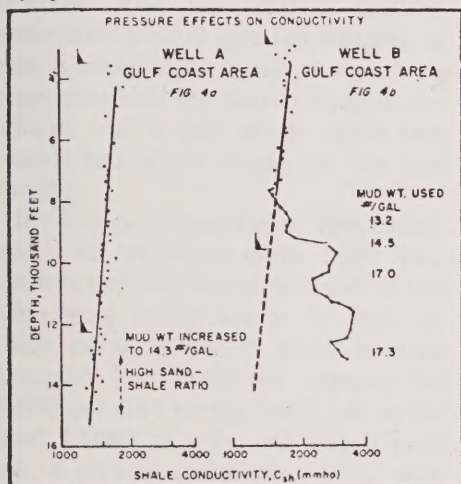
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SCHEMATIC RESPONSE OF WELL LOGGING PARAMETERS TO NORMAL PRESSURE AND OVERPRESSURE



These illustrations were taken from a paper entitled Implications of geotemperatures and geopressures in the search, drilling and production of hydrocarbons presented by D. J. Timko and W. H. Fertile at the Canadian Well Logging Society's fourth formation evaluation symposium, 1972.



otherwise noticeable upon penetration. The ideal situation is to carry a balanced mud system in which the weight of the mud column will just equal the force of the formation pressures. In practice, the mud weight will generally be slightly greater.

Geopressure zones fortunately, do not come in with a bang. Instead, a gradual buildup of pressure is the rule. The transitional zone leading to the superpressured zone can be thousands of feet thick or may measure only a few hundred feet. A tight caprock consisting of, for instance, limy shale, might lead to a relatively fast change of formation fluid pressures. Changes of nearly 5,000 psi over intervals of only a few hundred feet have been recorded. This is why it is so important "not to stumble over the first indication of geopressure conditions below." It could very quickly become a serious problem.

What is obviously needed is ex-

perience. But not only with the problem as such, rather also with local conditions. And local conditions could mean several areas within the same general environment, each of which display distinctly different pressure patterns at depth. In the Mackenzie Delta, for instance, north of a roughly east-northeast trending major fault zone, tough geopressure zones must be expected. On the seaward or northward side of the fault a major downward movement of sediments has occurred and the corresponding sedimentary section (i.e. the section which is younger than the initial fault movement) is accordingly very much thicker than landward from this line. All of Imperial's finds and most of the wells drilled, drilling or planned in the Delta region lie on the "high pressure side" of this major feature.

Experience requires time and co-operation. Viewed from the problem of

actual or possible encounter with geopressure zones, it makes sense to proceed with a drilling program on a step by step basis, allowing each subsequent hole to be better planned and drilled than the preceding one. This will not be the case if a great rush is underway, which was the normal situation with every play on the western plains. Prohibitive costs in the frontier areas tend to impose a cautious approach however, and the common interest of all competitors to avoid any misfortune in the fragile environment of the north tends to foster a hitherto unheard of degree of co-operation. A 17 pound plus mud weight is about that required in the Delta area and 18 pounds seems to be able to handle anything encountered in the Canadian frontier areas so far.

On the east coast, two depth levels of geopressure incidence have been reported. One occurs below 12,000 feet, and close to 15,000 feet, while in a string of other holes the normal gradient is upped to increasingly abnormal levels from the 8,000 to 10,000 foot interval.

In Mobil Oil's Sable island No. 1 well, the first hole drilled into the Scotian Shelf, the critical interval began at the base of the Naskapi Shale, from where the pressure gradient leaves its normal linear rise (normal gradient is generally thought of as 0.465 psi per foot of drilling depth or about the weight exerted by a column of sea water of same height). It might well be that the interval of transition is the same in all holes on the shelf, although no summarizing data on this has so far been released.

Geopressure zones are expensive to deal with and they do not necessarily indicate better pays. Most reserves seem to occur in intervals of slightly higher than normal pressure, but not in the very high pressure zones, although exceptions to the rule leave all of this outside the realm of affirmed knowledge.

Higher costs start with the casing. On the east coast the following pattern has been used: Start with 30-inch drive pipe to 100 feet; follow with 20-inch conductor pipe to about 600 feet; add about 3,500 feet of 13½-inch, 61 lbs/foot weight surface casing; try to get the 9½-inch intermediate casing string as deep as possible (S-95 grade, 40 lbs/ft). How far this can be carried depends on the

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GEOPRESSURE ZONES (Continued from page 44)

mud weight needed. Immediately below the surface casing, the formation pressure is tested for a pressure equivalent to mud weight four pounds higher than is being used. To be able to do this requires careful formation testing to establish the upper mud weight limit, and the carrying of ready mixed mud heavier than mud currently being circulated. Mobil, for instance, always has 400 barrels of ready-mixed mud standing by (about equivalent to 1½ complete systems at the prevailing depth of geopressure occurrence) with a mud weight two pounds above the mud weight being circulated. Wireline tests are run frequently, also normal wireline logs at critical depths, which together with mud readings, mud gas logger detector, and the normal drilling parameters tend to give fair warning of what is ahead of the bit. Once a gas kick is encountered, the heavier mud is circulated, and a new batch, again two pounds heavier, is mixed for the new standby.

Inside a geopressure zone, new casing has to be run about every 2,000 feet, which pretty well limits the depth of the hole. Next casing size is 7½-inch, at which point the BOP stack is also increased from 5,000 psi capacity to 10,000 psi (the casing itself will withstand 12,000 psi). In one East Coast well, a pressure gradient of 0.727 was encountered. This means that in the geopressure zone the pressure was equivalent to the weight of a column to that depth equivalent to 0.727 psi/foot of depth (while above this zone the normal 0.465 psi/ft would apply). As a precaution, double the required mud material is carried. Below surface casing to the base of the Naskapi Shale a mud weight of 9 to 10 will suffice, while the highest weight used in the Sable Island test was 15.5 lbs/gal.

To control possible geopressures, several lines of defence can be established.

Primary control includes every step from fortifying the hole and choosing the right mud to watching the hole while drilling. Prior knowledge of the area drilled will include a review of all records available and trying to arrive at predictions of what lies below. During the drilling operation indicators such as rock chip shape, drilling breaks, gas shows (mud logger), mud levels in tanks are recorded. A constant surveillance by

a fairly sophisticated array of instruments automatically checks mud levels, input/output ratios, gas content, etc.

In the second line of defence, the inside preventors and the BOP equipment are beefed up. Tertiary control involves sinking very heavy barite "plugs" or even cement plugs into the geopressure zone if everything else has failed. Imperial, for instance, once even used lead powder for such a plug. Problem is to mix it, get the material into suspension and into the hole. After it has settled, it can be drilled through.

The Mackenzie Delta area has peculiar problems close to the surface. The permafrost, for instance, has formed an effective barrier to formation fluid migration with the result that even surface holes have to be drilled with something heavier than just plain water.

After drilling through a geopressure zone, formation pressures revert back to their normal gradient, i.e. the pressure below a geopressure zone will be less. This also requires that casing be set through the geopressure zone so a lesser mud weight can be reverted to.

SPECIAL EQUIPMENT



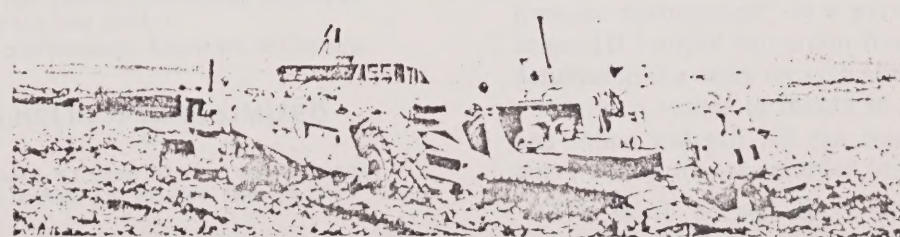
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Casing patterns in the Mackenzie Delta region for an exploratory hole include a 20-inch string as surface casing, followed by 16-inch, 13 $\frac{3}{8}$ -inch, 9 $\frac{1}{2}$ -inch, and 7 $\frac{1}{2}$ or 7-inch intermediate strings plus, perhaps, a five to 5 $\frac{1}{2}$ inch liner or last casing. As the delta play develops, operators will probably perfect procedures enough to cut out some of the intermediate casing strings. The toughest exploratory holes in the western provinces, i.e. in the foothills, would take, by comparison, a 13 $\frac{3}{8}$ -inch first string, followed by a 9 $\frac{1}{2}$ intermediate and 7 $\frac{1}{2}$ or 7 inch final string.

In the case of a development hole, casing diameter would drop one notch all the way down.

Geopressure zones are generally found in areas of rapid sedimentation typically in a Delta. As additional layers are deposited on top of the previous layers, formation waters are squeezed out as a result of overburden pressure. But these fluids may also become trapped, by a calcareous shale, for instance, in a sand/shale sequence (a pressure drop in sand layer above this shale might cause the calcareous and

sealing precipitation). This can then, with further burial, lead to quite a pressure buildup. Laterally faults might delineate the zone of this occurrence. And the whole thing could be subjected to other movements or geopressured shale might cause shale diapirs itself.

The geopressure zones manifest themselves by higher than normal formation pressures and also by higher than normal temperatures. Both characteristics have a number of effects, notably on drilling rates and well logs, which can be measured and recorded and which provide tools for warning and correlation.

For one thing, the shales encountered will be less dense. This is the reason why bulk density of shales is measured as a routine from chips returned to the shale shaker. This is a somewhat imprecise observation, since the composition of shales may well change with distance from one hole to the next, and each change in composition means, of course, a change in density. A better method might be to measure porosity of the shales.

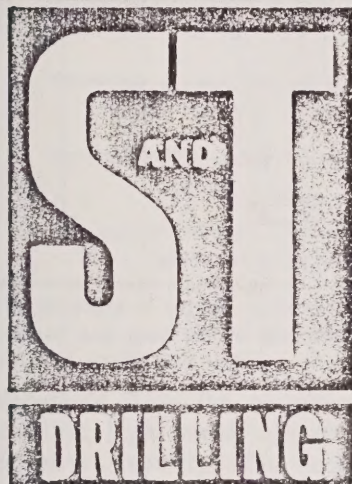
Drilling will speed up since less matrix is to be cut in a rock which also contains far more formation fluid. The gas detector will act up, the temperature of the mud will rise, but this is rather imprecise since dependent on surface conditions.

Temperature measurements become quite valuable when logs are run, and the bottomhole temperature is taken at the same time.

Earlier this year the Fourth Formation Evaluation Symposium of the Canadian Well Logging Society heard a paper by D. J. Timko and W. H. Fertl on the "implication of geotemperatures and geopressures in the search, drilling and production of hydrocarbons." This paper gives a short but complete run-down of the log curves useful in the detection of geopressure zones.

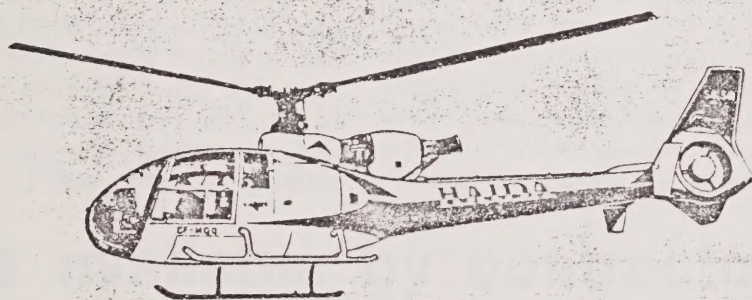
The SP curve will record "a rather marked freshening of salinities several hundred feet above and in the abnormal pressure environment" in a permeable zones. (If trapped formation fluids are assumed as the cause for such abnormal pressures it stands to reason to expect less saline waters.) All the other log curve indicators are recorded in shales.

The short normal curve shows a
(Continued on page 51)



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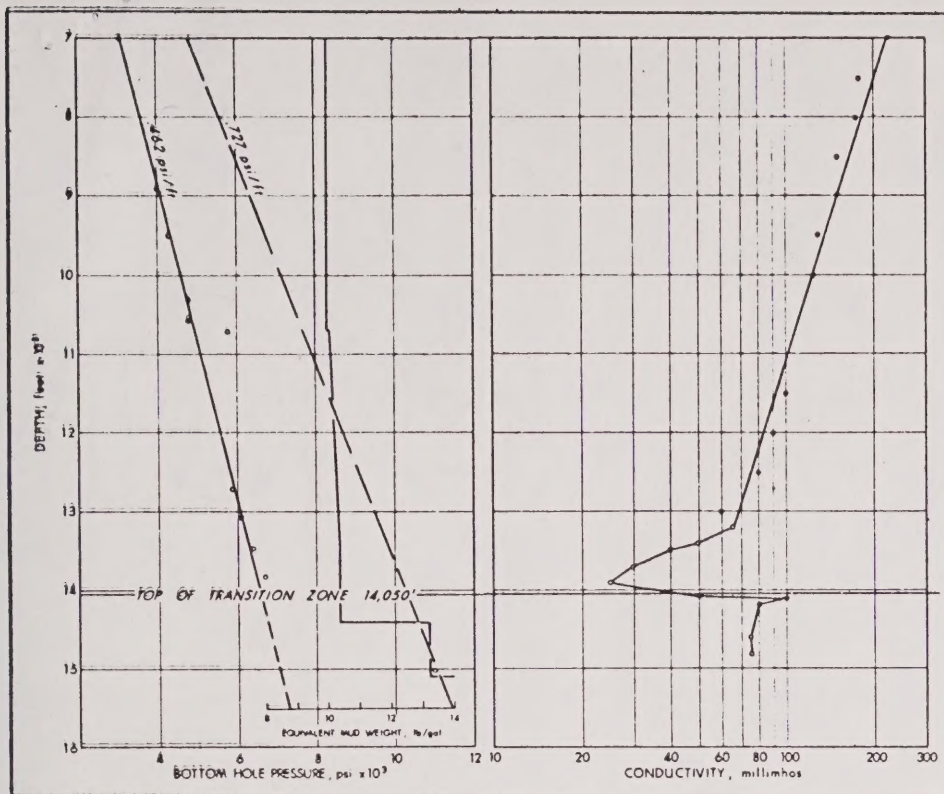
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The decrease in logged conductivity near the top of the transition zone to the geopressure interval and mud weight adjustments to contain the pressure are shown in this example from an east coast well.

departure from the normal trend indicating high water content and increasing porosity. The conductivity curve shows higher values for the same reasons. Acoustic interval measurements will be affected by the significant increase in porosity in overpressured shales (while the log is unaffected by changes in the hole size, temperature and salinity). Bulk density decreases may be masked by hole washouts. Pulsed neutron measure-

ments can read behind the pipe and direct attention to formation fluid migrations, pressure depletion, etc.

Operators in the frontier regions have plotted the various log indicators from known wells against mud weight requirements and have come up with quite usable curves, notably for the conductivity curve, sonic log and also the drillability curve recorded and computed by the modern rig sensors.

Rigs available by contractor, model number, depth rating

With at least eight new drilling rigs purchased during 1972, contractors feel more optimistic about future trends than for several years past.

The number of rigs available for operation at Nov. 15 this year was 319, one more than the 317 listed at the same date in 1971. Although all the problems of the drilling business are not over, the pace of well completions, footage drilled and rig operating days has shown a remarkable gain over last year. There are high expectations for a long-term firm trend.

At mid-November the rigs listed below were more than 60 per cent

active, with 160 drilling, 28 moving in and one rigging up, while only 130 were idle. It is expected almost complete utilization of available rigs will be achieved in the winter peak season and crews will be found to staff them.

Drilling rig census

Rig No. Capacity Rig Type

AMC Drilling Division

44	18,000	National 1320 M
45	11,000	Emsco GC 500
46	22,000	National 1320 UE
48	18,000	National 110

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1	5,500	National T-20
2	7,000	National T-32

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